Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
12 (2008) 344–371
RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS
www.elsevier.com/locate/rser

Ground-source heat pumps systems and applications

Abdeen Mustafa Omer*

17 Juniper Court, Forest Road West, Nottingham NG7 4EU, UK

Received 28 July 2006; accepted 13 October 2006

Abstract

Ground-source or geothermal heat pumps are a highly efficient, renewable energy technology for space heating and cooling. This technology relies on the fact that, at depth, the Earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. A geothermal heat pump can transfer heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer. Special geologic conditions, such as hot springs, are not needed for successful application of geothermal heat pumps. Ground-source heat pumps (GSHPs) are receiving increasing interest because of their potential to reduce primary energy consumption and thus reduce emissions of greenhouse gases. The technology is well established in North America and parts of Europe, but is at the demonstration stage in the UK. This article provides a detailed literature-based review of ground-source heat pump technology, concentrating on loops, ground systems, and looks more briefly at applications and costs and benefits. It concludes with the prospects for GSHP in the UK. It is concluded that, despite potential environmental problems, geothermal heat pumps pose little if any serious environmental risk when best management practices are applied during the installation, operation, and decommissioning of these systems.

Keywords: Ground-source; Heat pumps; Loops; Applications

Contents

*Tel.: +44 115 978717.
E-mail address: abdeenomer2@yahoo.co.uk

1364-0321/$ - see front matter
doi:10.1016/j.rser.2006.10.003

1. Introduction

Climate change is a real threat to our future, and a major cause is the use of fossil fuels to power homes and businesses. Renewable energy, combined with energy efficiency, offers a viable and potent solution to countering the effects of global warming. By installing any one of the renewable energy technologies, one will be making a major personal contribution to the well being of future generations and could also benefit from lower fuel bills.

Our natural sense of heat is based rather more on instinct than on science. Humans are warm-blooded and judge "heat" by comparing it to touch. Since our body temperatures need to be maintained within a few degrees centigrade, our natural senses have evolved to make extremes of temperature uncomfortable. To us, a hot summer's day feels many times "hotter" than the freezing mid-winter. But in reality the Earth's surface does not vary in "heat energy" as much as we might imagine. Scientifically speaking, there is only 11% less energy in cold river water at 5 °C (40 °F) compared to hot bath water at 40 °C (105 °F) [1].

Ground-source heat pumps (GSHPs) provide a new and clean way of heating buildings in the world. They make use of renewable energy stored in the ground, providing one of the most energy-efficient ways of heating buildings. They are suitable for a wide variety of building types and are particularly appropriate for low environmental impact projects. They do not require hot rocks (geothermal energy) and can be installed in most of the

world, using a borehole or shallow trenches or, less commonly, by extracting heat from a pond or lake. Heat collecting pipes in a closed loop, containing water (with a little antifreeze) are used to extract this stored energy, which can then be used to provide space heating and domestic hot water. In some applications, the pump can be reversed in summer to provide an element of cooling.

The only energy used by GSHP systems is electricity to power the pumps. Typically, a GSHP will deliver three or four times as much thermal energy (heat) as is used in electrical energy to drive the system. For a particularly environmental solution, green electricity can be purchased. GSHP systems have been widely used in other parts of the world, including North America and Europe, for many years. Typically they cost more to install than conventional systems; however, they have very low maintenance costs and can be expected to provide reliable and environmentally friendly heating for in excess of 20 years. GSHPs work best with heating systems, which are optimised to run at a lower water temperature than is commonly used in the UK boiler and radiator systems. As such, they make an ideal partner for underfloor heating systems.

Heat pumps offer the most energy-efficient way to provide heating and cooling in many applications, as they can use renewable heat sources in our surroundings. Even at temperatures we consider to be cold, air, ground and water contain useful heat that is continuously replenished by the sun. By applying a little more energy, a heat pump can raise the temperature of this heat energy to the level needed. Similarly, heat pumps can also use waste heat sources such as from industrial processes, cooling equipment or ventilation air extracted from buildings. A typical electrical heat pump will just need 100 kWh of power to turn 200 kWh of freely available environmental or waste heat into 300 kWh of useful heat. Because heat pumps consume less primary energy than conventional heating systems, they are an important technology for reducing emissions of gases that harm the environment, such as carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x). However, the overall environmental impact of electric heat pumps depends very much on how the electricity is produced. Heat pumps driven by electricity from, for instance, hydropower or renewable energy reduce emissions more significantly than if the electricity is generated by coal, oil or gas-fired power plants.

Geothermal heating can be more efficient than electric resistance heating. These systems are also typically more efficient than gas or oil-fired heating systems. They are more energy efficient than air-source heat pumps because they draw heat from, or release heat to, the earth, which has moderate temperatures year round, rather than to the air (which is generally colder in winter and warmer in summer than the earth, resulting in less effective heat transfer). It is argued that heat pumps are highly energy efficient, and therefore environmentally benign.

2. Earth-energy systems

Renewable forms of energy such as solar, wind, biomass, hydro, and earth energy produce low or no greenhouse gas (GHG) emissions. Geothermal heating and cooling systems (also called earth-energy systems (EESs), GSHPs or GeoExchange systems) are heat pumps that collect and transfer heat from the earth through a series of fluid-filled, buried pipes running to a building, where the heat is then concentrated for inside use. GSHPs do not create heat through combustion—they simply move heat from one place to another.

Principal aims are to:

- Promote the concept of using GSHPs as an environmentally preferable means of heating and cooling buildings.
- Assist in developing standards for, and provide support to, the growing industry of manufacturers, importers and installers of GSHPs.

Heat pumps also operate in reverse to cool a home by transferring the heat out of the house, where the cooler ground absorbs the excess heat. The system is appealing because a single system can be used for both heating and cooling, thus eliminating the need for separate furnace and air-conditioning systems.

GSHPs offer a different kind of heating. Unlike conventional forced-air furnaces, geothermal units offer a steady heat. There is no "blast" of hot air—it provides a constant heat and it is a clean heat—there is no residue or dust around the house like there was with a forced-air heating systems in homes in big cities. Geothermal units are also extremely efficient in cooling homes.

Also called an earth-coupled heat pump, or a geothermal heat pump, a GSHP operates much like the common air-source heat pump by transferring heat, rather than creating it. Unlike air-source, a GSHPs transfers heat to and from the earth to provide cooling and heating for homes. Below the frost line, the temperature of the earth in Nebraska stays fairly constant at 55 °F. In summer, the soil temperature is cooler than the outside air. In winter, it is warmer. A GSHP uses this constant temperature to heat and cool homes very efficiently.

A GSHP uses the earth or ground water or both as the sources of heat in the winter, and as the "sink" for heat removed from the home in the summer. For this reason, GSHP systems have come to be known as EESs. Heat is removed from the earth through a liquid, such as ground water or an antifreeze solution, upgraded by the heat pump, and transferred to indoor air. During summer months, the process is reversed: heat is extracted from indoor air and transferred to the earth through the ground water or antifreeze solution. A direct-expansion (DX) EES uses refrigerant in the ground-heat exchanger, instead of an antifreeze solution.

EESs are available for use with both forced-air and hydronic heating systems. They can also be designed and installed to provide heating only, heating with "passive" cooling, or heating with "active" cooling. Heating-only systems do not provide cooling. Passive-cooling systems provide cooling by pumping cool water or antifreeze through the system without using the heat pump to assist the process.

2.1. Geothermal energy

Greater use of renewable energy and increased energy efficiency are considered key to limiting GHG emissions.

EESs such as

- GSHPs,
- geoExchange, or
- geothermal heat pump systems

are considered to be the most energy-efficient, environmentally clean and cost-effective heating and cooling systems available.

2.2. Clean energy sources

Wind, solar, biomass, and water are not the only sources of clean, environmentally friendly energy. Other energy sources can also provide heat, light, and electricity without polluting the air or disturbing large areas of land or water. This backgrounder covers a few of these new technologies, some of which are likely to become mainstream sources of energy in the approaching decades (Fig. 1).

The temperature of the ground is fairly constant below the frost line. The ground is warmer in the middle of winter and cooler in the middle of summer than the outside air. A single efficient system can be used for both heating and cooling, eliminating the need for separate furnace and air-conditioning systems. It can also heat water at no additional cost. An EES uses a series of buried pipes to transfer the heat from the ground into a building during winter, converting it into warm air and distributing it through ducts. In summer, the system is reversed to transfer heat out of the building, where it uses the cooler ground as a heat sink. The system can be configured as either a closed or open loop, and the loop itself can be either horizontal or vertical. Closed-loop systems circulate a fluid mixture within the buried pipes, while open-loop systems circulate well or surface water.

GSHPs do not create heat through combustion; they simply move solar heat that is stored in soil or water from one place to another.

- GSHPs can reduce GHG emissions by 66% or more compared with conventional heating and cooling systems that use fossil fuels.
- EESs use up to 75% less electricity than conventional heating or cooling systems.
- Maintenance costs for this type of technology can be cut in half and operating costs reduced one-quarter of that of a conventional system.

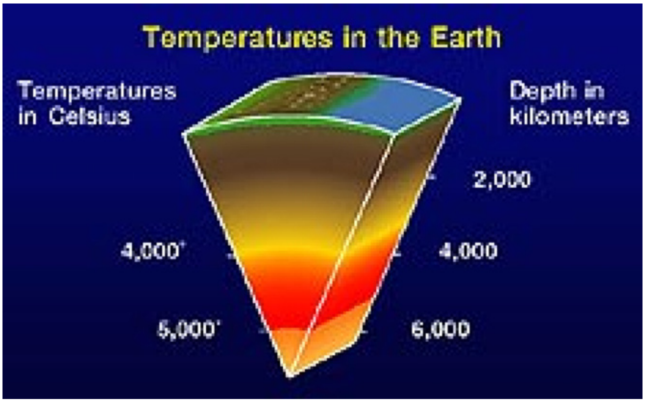

Fig. 1. Geothermal heat comes from pressure and nuclear reactions at the earth's core.

2.3. Geothermal heat

People have known since ancient times that the Earth's interior is very hot. The temperature of the Earth's core is estimated to be between 3000 and 5000 °C (scientists are still not sure what the exact temperature is). This heat is generated by the slow breakdown of radioactive elements, and by the immense gravitational pressures acting on the rocks and minerals of the Earth's interior. Temperatures in excess of 500 °C can be found in the Earth's crust just a few thousand metres below the surface, but geothermal heat right at the surface of the land is barely detectable [2].

Geothermal heat has been used to heat homes and businesses on a commercial scale since the 1920s. In most cases, communities take advantage of naturally occurring geysers, hot springs, and steam vents (called fumaroles) to gather hot water and steam for heating. Geysers and fumaroles occur when ground water seeps through cracks and comes in contact with volcanically heated rocks. In Iceland for instance, wells are drilled into volcanic rocks to extract hot water and steam. The hot water or steam is carried to communities in insulated pipes and used to heat homes and businesses. In some cases, the water is superheated (heated under pressure to temperatures greater than 100 °C). Superheated water quickly turns to high-pressure steam, which can turn high-speed turbines that drive electrical generators.

Ground-source or geothermal heat pumps are a highly efficient, renewable energy technology for space heating and cooling. This technology relies on the fact that, at depth, the Earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. A geothermal heat pump can transfer heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer. These types of geothermal heat pumps are suitable for use throughout Illinois and the Midwest. Special geologic conditions, such as hot springs, are not needed for successful application of geothermal heat pumps.

A geothermal heat pump includes three principle components—an earth connection subsystem, heat pump subsystem, and heat distribution subsystem. The earth connection subsystem usually includes a closed loop of pipes that is buried, horizontally or vertically. A fluid is circulated through these pipes, allowing heat but not fluid to be transferred from the building to the ground. The circulating fluid is generally water or a water/antifreeze mixture. Less commonly, the earth connection system includes an open loop of pipes connected to a surface water body or an aquifer, that directly transfers water between the heat exchanger and water source (pond or aquifer).

For heating, the heat pump subsystem removes heat from the circulated fluid, concentrates it, and transfers it to the building. For cooling, the process is reversed. The heat distribution subsystem is the conventional ductwork used to distribute heated or cooled air throughout a building. The US Department of Energy (USDOE) estimated that over two-thirds of the nation's electrical energy and greater than 40% of natural gas consumption is used inside buildings. In residential and commercial buildings, space heating and cooling and water heating consume greater than 40% of electrical power. The US Environmental Protection Agency (USEPA) estimated that geothermal heat pumps can reduce energy consumption by up to 44% compared to air-source heat pumps and up to 72% compared to conventional electrical heating and air conditioning. For most areas of the US, geothermal heat pumps are the most energy-efficient means of heating and cooling buildings [3].

For vertical, closed-loop systems, heat exchange between the fluid and ground depends upon the thermal properties of the material in the borehole. The borehole may be backfilled with soil cuttings or grout. In Illinois, the borehole must be backfilled with bentonite grout or neat cement. Standard bentonite grout has a thermal conductivity that is lower than most soils or geologic materials (0.43 BTU/h ft °F vs. 0.8–1.8 BTU/h ft °F), thus it acts as an insulator around the heat exchange pipes [4]. Thermally enhanced bentonite grouts have been developed and have thermal conductivities of 0.85–1.4 BTU/h ft °F [5], while retaining low hydraulic conductivity ($<10-7$ cm/s), based on technical data from manufacturers. To boost the thermal conductivity of grouts, manufacturers mix silica sand and bentonite, and at times other materials such as cement and superplasticiser [6].

3. Heat pump efficiency

A heat pump can save as much as 30%–40% of the electricity used for heating. If you use electricity to heat homes, consider installing an energy-efficient heat pump system. Heat pumps are the most efficient form of electric heating in mild and moderate climates, providing two to three times more heating than the equivalent amount of energy they consume in electricity. Air source heat pumps are recommended for mild and moderate climate regions, where the winter temperatures usually remain above 30 °F. Ground source (also known as geothermal) heat pumps are more efficient and economical to operate when compared to conventional air source heat pumps, especially in climates with similar heating and cooling loads. Three types of heat pumps are typically available for residences: (1) air-to-air, (2) water source, and (3) ground source. Heat pumps collect heat from the air, water, or ground outside homes and concentrate it for use inside the house. Heat pumps operate in reverse to cool your home by collecting the heat inside your house and effectively pumping it outside [7].

Heat pumps have both heating and cooling ratings—both in terms of capacity and efficiency. Capacity ratings are generally in British thermal unit (Btu) per hour or tons (one ton equals 12,000 Btu/h). Heating efficiency for air source heat pumps is indicated by the heating season performance factor (HSPF). The HSPF tells the ratio of the seasonal heating output in Btu's divided by the seasonal power consumption in Watt-hours. A heat pump can supply two to three times as much heat as it consumes in electricity because it moves energy from outside to inside (or vice versa). Heat pump efficiency varies with outdoor temperature. The performance of an air source heat pump in heating mode decreases with the drop in outside air temperature. The actual seasonal efficiency (as opposed to the rating) is therefore higher in a mild climate than in a severe cold climate. In the cooling mode, a heat pump operates exactly like a central air conditioner. The seasonal energy efficiency ratio (SEER) is analogous to the HSPF but tells the seasonal cooling performance. Federal efficiency standards require that conventional heat pumps have an HSPF rating of at least 6.8 and a SEER rating of at least 10.0. The most efficient air source heat pumps have an HSPF rating between 9.0 and 10.0 and a SEER above 14 or so (Table 1).

3.1. Energy efficiency considerations

As with air-source heat pumps, EESs are available with widely varying efficiency ratings. EESs (EER) intended for groundwater or open-system applications have heating COP ratings ranging from 3.0 to 4.0, and cooling EER ratings between 11.0 and 17.0. Those

Table 1
Comparison of different heating systems

System	Primary energy efficiency (%)	CO_2 emissions (kg CO_2/kWh heat)
Oil fired boiler	60–65	0.45–0.48
Gas fired boiler	70–80	0.26–0.31
Condensing gas boiler + low temperature system	100	0.21
Electrical heating	36	0.9
Conventional electricity + GSHP	120–160	0.27–0.20
Green electricity + GSHP	300–400	0.00

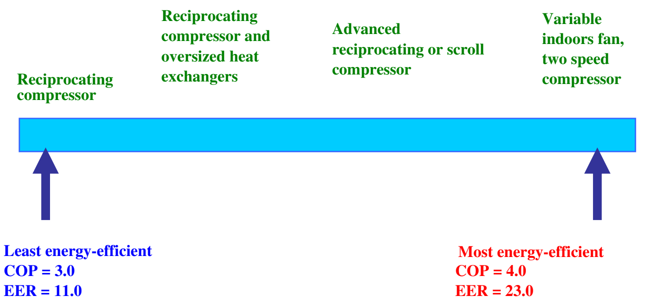

Fig. 2. Open system earth-energy system efficiency (at an entering water temperature of 10 °C).

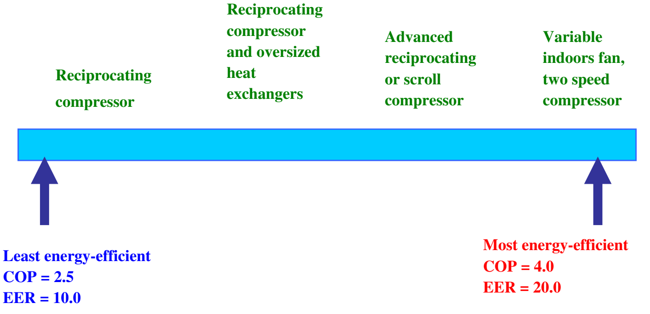

Fig. 3. Open system earth-energy system efficiency (at an entering water temperature of 10 °C).

intended for closed-loop applications have heating COP ratings between 2.5 and 4.0, while EER ratings range from 10.5 to 20.0 [7].

The minimum efficiency in each range is regulated in the same jurisdictions as the air-source equipment. There has been a dramatic improvement in the efficiency of EESs efficiency over the past 5 years. Today, the same new developments in compressors, motors, and controls that are available to air-source heat pump manufacturers are resulting in higher levels of efficiency for EESs (Figs. 2 and 3).

In the lower to middle efficiency range, EESs use single-speed rotary or reciprocating compressors, relatively standard refrigerant-to-air ratios, but oversized enhanced-surface refrigerant-to-water heat exchangers. Mid-range efficiency units employ scroll compressors

or advanced reciprocating compressors. Units in the high efficiency range tend to use two-speed compressors or variable speed indoor fan motors or both, with more or less the same heat exchangers.

4. Heat pumps

One of the most energy-efficient methods of domestic heating is to use heat pumps. Heat pumps use electrical energy to reverse the natural flow of environmental heat from cold to hot. A typical heat pump requires only 100 kWh of electrical power to turn 200 kWh of freely available environmental heat into 300 kWh of useful heat. In every case, the useful heat output will be greater than the energy required to operate the pump itself. Heat pumps also have a relatively low carbon dioxide output, less than half than that of electric, oil and gas heat production. Heat pumps for domestic heating are a relatively new concept in Britain, however the technology is widely used in an industrial capacity. Across Europe, hundreds of thousands of domestic heat pump units are in use, and the technology is tried, tested and reliable [8].

GSHPs transfer heat from the ground into a building to provide space heating (Fig. 4) and, in some cases, to pre-heat domestic hot water. For every unit of electricity used to pump the heat, 3–4 units of heat are produced. As well as GSHPs, air source and water source heat pumps are also available.

There are three important elements to a GSHP:

(1) The ground loop

This is comprised of lengths of pipe buried in the ground, either in a borehole or a horizontal trench. The pipe is usually a closed circuit and is filled with a mixture of water and antifreeze, which is pumped round the pipe absorbing heat from the ground.

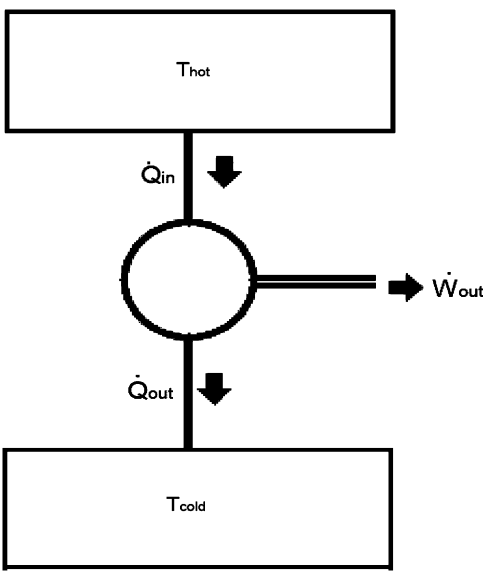

Fig. 4. Diagram of heat engine.

(2) A heat pump
This has three main parts:

- The evaporator—(e.g., the squiggly thing in the cold part of the fridge) takes the heat from the water in the ground loop.
- The compressor—(this is what makes the noise in a fridge) moves the refrigerant round the heat pump and compresses the gaseous refrigerant to the temperature needed for the heat distribution circuit.
- The condenser—(the hot part at the back of the fridge) gives up heat to a hot water tank, which feeds the distribution system.

(3) Heat distribution system
Consisting of under floor heating or radiators for space heating and in some cases water storage for hot water supply.

The ground loop can be:

(1) Borehole.
(2) Straight horizontal—trench costs less than a borehole, but needs more land area.
(3) Spiral horizontal (or 'slinky coil')—needs a trench of about 10 m length to provide about 1 kW of heating load.

Refrigeration is the 'artificial' extraction of heat from a substance in order to lower its temperature to below that of its surroundings. Primarily, heat is extracted from fluids such as air and many liquids, but ultimately from any substance. In order to extract heat a region of 'cold' has to be created. A number of effects can be used:

- The Peltier effect (reverse of thermocouples).
- Endothermic chemical reactions.
- Induced vaporisation of a liquid.

In thermodynamic terms a refrigerator is a reversed heat engine i.e., heat may transfer from a cold reservoir to a hot reservoir by expending work (Fig. 5).

A heat pump is no different in principle from a refrigerator apart from its purpose. A heat pump is used to provide 'heat' whereas a refrigerator is used to obtain 'cold'.

4.1. The technical view of the heat pump process

A heat pump is a mechanical device used for heating and cooling, which operates on the principle that heat can be moved from a warmer temperature to a cooler temperature. A GSHP uses the earth to warm in the winter and cool in the summer. Anyone already has a heat pump in home—a refrigerator. If you put your hand behind it you will feel the heat that has been removed from the food inside the refrigerator. This is the same principle that is used to move heat to and from the home and earth. The heat pump moves heat from a low temperature source to a high temperature source. The process of elevating low temperature heat to over 100 °F (38 °C) and transferring it indoors involves a cycle of evaporation, compression, condensation and expansion. A non-CFC refrigerant is used as the heat-transfer medium, which circulates within the heat pump (Fig. 6).

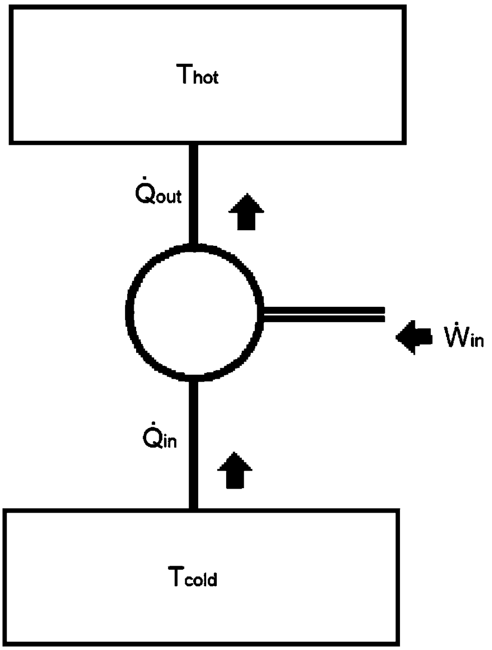

Fig. 5. Reserved heat engine (refrigerator).

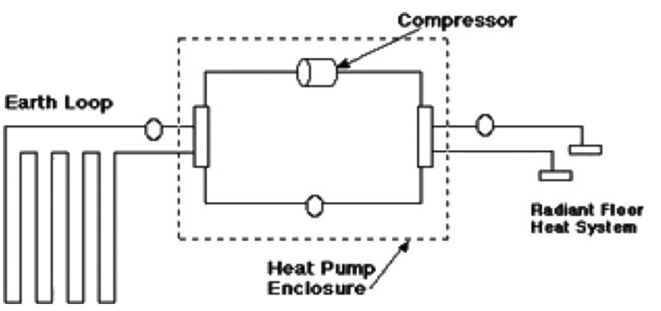

Fig. 6. Heat pump cycles.

The major barriers to rapid implementation of this technology involve awareness and acceptance by users and HVAC designers (which is growing rapidly) and higher initial implementation costs than other options. In addition, there is a limited infrastructure and availability of skilled and experienced designers and installers of GSHP systems.

Installation costs vary depending on the design and application, but typically range between \$1500 and \$3000/ton (\$425 and \$840/kW). GSHPs have the potential to reduce cooling energy by 30% to 50% and reduce heating energy by 20% to 40% [9]. GSHPs tend to be more cost-effective than conventional systems in the following applications:

- In new construction where the technology is relatively easy to incorporate, or to replace an existing system at the end of its useful life.

- In climates characterised by high daily temperature swings, or where winters are cold or summers hot, and where electricity cost is higher than average.
- In areas where natural gas is unavailable or where the cost is higher than electricity.

The following cautions are recommended for any GSHP application under consideration:

- Install as a complete system, with the system and each unit properly designed and sized.
- Use only experienced and certified installers.
- Analyse soil type and thermal conductivity, if appropriate.
- Be aware that local water and well regulations may restrict some system types.
- Obtain equipment and installation warranties.

GSHPs are known by a variety of names: GeoExchange heat pumps, ground-coupled heat pumps, geothermal heat pumps, earth-coupled heat pumps, ground-source systems, groundwater source heat pumps, well water heat pumps, solar energy heat pumps, and a few other variations. Some names are used to describe more accurately the specific application; however, most are the result of marketing efforts and the need to associate (or disassociate) the heat pump systems from other systems.

A typical GSHP system design applied to a commercial facility is illustrated in Fig. 6. It is important to remember that the primary equipment used for GSHPs are water-source heat pumps. What makes a GSHP different (unique, efficient, and usually more expensive to install) is the ground-coupling system. In addition, most manufacturers have developed extended-range water source heat pumps for use as GSHPs.

A conventionally designed water-source heat pump system would incorporate a boiler as a heat source during the winter heating operation and a cooling tower to reject heat (heat sink) during the summer cooling operation. This system type is also sometimes called a boiler/tower water-loop heat pump system. The water loop circulates to the entire water source heat pumps connected to the system. The boiler (for winter operation) and the cooling tower (for summer operation) provide a fairly constant water-loop temperature, which allows the water-source heat pumps to operate at high efficiency.

A conventional air-source heat pump uses the outdoor ambient air as a heat source during the winter heating operation and as a heat sink during the summer cooling operation. Air-source heat pumps are subject to higher temperature fluctuations of the heat source and heat sink. They become much less effective—and less efficient—at extreme ambient air temperatures. This is particularly true at low temperatures. In addition, heat transfer—using air as a transfer medium is not as effective as water systems because of air's lower thermal mass.

A GSHP uses the ground (or in some cases groundwater) as the heat source during the winter heating operation and as the heat sink during the summer cooling operation. GSHPs may be subject to higher temperature fluctuations than conventional water-source heat pumps but not as high as air-source heat pumps. Consequently, most manufacturers have developed extended-range systems. The extended-range systems operate more efficiently while subject to the extended-temperature range of the water loop. Like water-source heat pumps, GSHPs use a water loop between the heat pumps and the heat source/heat sink (the earth). The primary exception is the DX GSHP. GSHPs take advantage of the thermodynamic properties of the earth and groundwater. Temperatures

below the ground surface do not fluctuate significantly through the day or the year, as do ambient air temperatures. Ground temperatures a few feet below the surface stay relatively constant throughout the year. For this reason, GSHPs remain extremely efficient throughout the year in virtually any climate.

5. Description of ground-source types for heat pump

The ground system links the heat pump to the underground and allows for extraction of heat from the ground or injection of heat into the ground. These systems can be classified generally as open or closed systems, with a third category for those not truly belonging to one or the other.

Open systems: Groundwater is used as a heat carrier, and is brought directly to the heat pump. Between rock/soil, ground water, and the heat pump evaporator is no barrier, hence this type is called "open".

Closed systems: Heat exchangers are located in the underground (either in a horizontal, vertical or oblique fashion), and a heat carrier medium is circulated within the heat exchangers, transporting heat from the ground to the heat pump (or vice versa). The heat carrier is separated from the rock/soil and groundwater by the wall of the heat exchanger, making it a "closed" system.

Other systems: Not always the system can be attributed exactly to one of the above categories, e.g., if there is a certain distinction between groundwater and the heat carrier fluid, but no true barrier. Standing column wells, mine water or tunnel water are examples for this category.

To choose the right system for a specific installation, several factors have to be considered: geology and hydrogeology of the underground (sufficient permeability is a must for open systems), area and utilisation on the surface (horizontal closed systems require a certain area), existence of potential heat sources like mines, and the heating and cooling characteristics of the building(s). In the design phase, more accurate data for the key parameters for the chosen technology are necessary; to size the ground system in such a way that optimum performance is achieved with minimum cost. The individual types of ground systems are described in more detail as following:

5.1. Closed systems

5.1.1. Horizontal-loop systems

The closed system easiest to install is the horizontal ground heat exchanger (synonym: ground heat collector, horizontal loop). Due to restrictions in the area available, in Western and Central Europe the individual pipes are laid in a relatively dense pattern, connected either in series or in parallel (Fig. 7).

For the ground heat collectors with dense pipe pattern, usually the top earth layer is removed completely, the pipes are laid, and the soil is distributed back over the pipes. In Northern Europe (and in North America), where land area is cheaper, a wide pattern ("loop") with pipes laid in trenches is preferred (Fig. 8). Trenching machines facilitate installation of pipes and backfilling.

To save surface area with ground heat collectors, some special ground heat exchangers have been developed. Exploiting a smaller area at the same volume, these collectors are best suited for heat pump systems for heating and cooling, where natural temperature

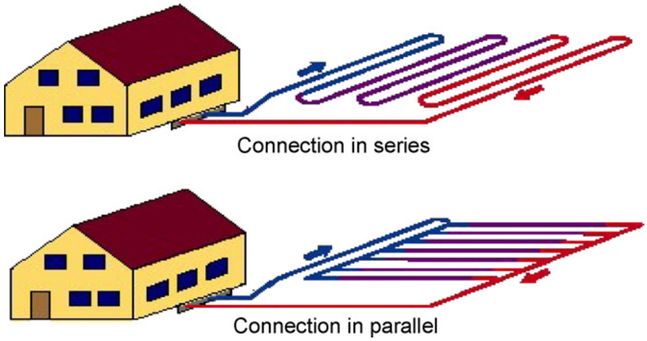

Fig. 7. Horizontal ground heat exchanger (European style).

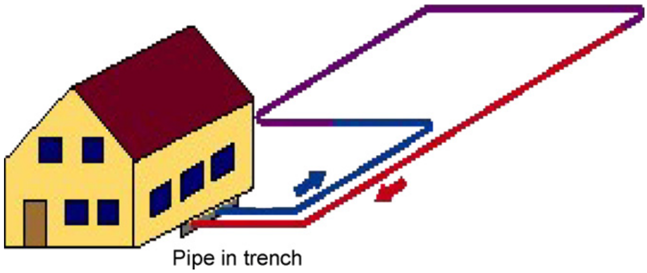

Fig. 8. Horizontal ground heat exchanger (North European and American style).

recharge of the ground is not vital. Hence these collectors are widely used in Northern America, and one type only, the trench collector (Fig. 9), achieved a certain distribution in Europe, mainly in Austria and Southern Germany. For the trench collector, a number of pipes with small diameter are attached to the steeply inclined walls of a trench some meters deep.

The main thermal recharge for all horizontal systems is provided for mainly by the solar radiation to the earth's surface. It is important not to cover the surface above the ground heat collector, or to operate it as a heat store, if it has to be located e.g., under a building. A variation of the horizontal GSHP is direct expansion. In this case, the working medium of the heat pump (refrigerant) is circulating directly through the ground heat collector pipes (in other words, the heat pump evaporator is extended into the ground). The advantage of this technology is the omission of one heat exchange process, and thus a possibility for better system efficiency. In France and Austria, direct expansion also has been coupled to direct condensation in the floor heating system. DX requires good knowledge of the refrigeration cycle, and is restricted to smaller units. The horizontal-loop systems can be buried beneath lawns, landscaping, and parking lots. Horizontal systems tend to be more popular where there is ample land area with a high water table.

- *Advantages*: Trenching costs typically lower than well-drilling costs; flexible installation options.
- *Disadvantages*: Large ground area required; ground temperature subject to seasonal variance at shallow depths; thermal properties of soil fluctuate with season, rainfall, and

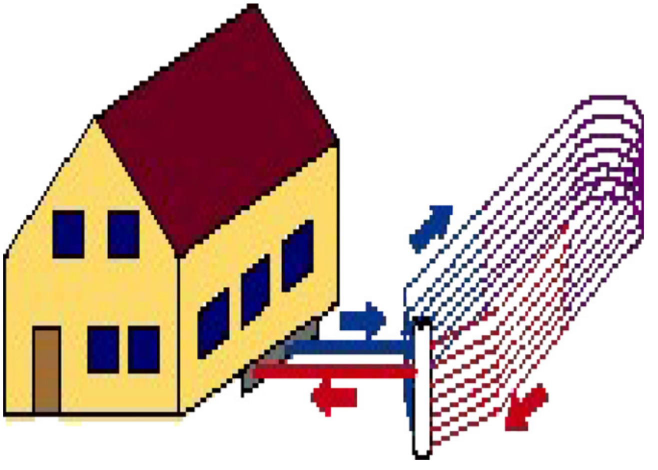

Fig. 9. Trench collector.

burial depth; soil dryness must be properly accounted for in designing the required pipe length, especially in sandy soils and on hilltops that may dry out during the summer; pipe system could be damaged during backfill process; longer pipe lengths are required than for vertical wells; antifreeze solution viscosity increases pumping energy, decreases the heat-transfer rate, and thus reduces overall efficiency; lower system efficiencies.

5.2. Spiral loops

A variation on the multiple pipe horizontal-loop configuration is the spiral loop, commonly referred to as the "slinky". The spiral loop consists of pipe unrolled in circular loops in trenches and the horizontal configuration. Another variation of the spiral-loop system involves placing the loops upright in narrow vertical trenches. The spiral-loop configuration generally requires more piping, typically 500 to 1000 ft per system cooling ton (43.3 to 86.6 m/kW) but less total trenching than the multiple horizontal-loop systems described above. For the horizontal spiral-loop layout, trenches are generally 3 to 6 ft (0.9 to 1.8 m) wide; multiple trenches are typically spaced about 12 ft (3.7 m) apart. For the vertical spiral-loop layout, trenches are generally 6 in (15.2 cm) wide; the pipe loops stand vertically in the narrow trenches. In cases where trenching is a large component of the overall installation costs, spiral-loop systems are a means of reducing the installation cost. As noted with horizontal systems, slinky systems are also generally associated with lower-tonnage systems where land area requirements are not a limiting factor.

- *Advantages*: Requires less ground area and less trenching than other horizontal-loop designs; installation costs sometimes less than other horizontal-loop designs.
- *Disadvantages*: Requires more total pipe length than other ground coupled designs; relatively large ground area required; ground temperature subject to seasonal variance; larger pumping energy requirements than other horizontal loops defined above; backfilling the trench can be difficult with certain soil types and the pipe system could be damaged during backfill process.

5.3. Vertical loops

As can be seen from measurements dating as far back as to the 17th century, the temperature below a certain depth (“neutral zone”, at ca. 15–20 m depth) remains constant over the year. This fact, and the need to install sufficient heat exchange capacity under a confined surface area, favours vertical ground heat exchangers (borehole heat exchangers). In a standard borehole heat exchanger, plastic pipes (polyethylene or polypropylene) are installed in boreholes, and the remaining room in the hole is filled (grouted) with a pumpable material. In Sweden, boreholes in hard, crystalline rock usually are kept open, and the groundwater serves for heat exchange between the pipes and the rock. If more than one borehole heat exchanger is required, the pipes should be connected in such a way that equal distribution of flow in the different channels is secured. Manifolds can be in or at the building, or the pipes can be connected in trenches in the field (Fig. 10).

Several types of borehole heat exchangers have been used or tested; the two possible basic concepts are:

- U-pipes, consisting of a pair of straight pipes, connected by a 180° turn at the bottom. One, two or even three of such U-pipes are installed in one hole. The advantage of the U-pipe is low cost of the pipe material, resulting in double U pipes being the most frequently used borehole (Fig. 10.9).
- Coaxial (concentric) pipes, either in a very simple way with two straight pipes of different diameter, or in complex configurations heat exchangers in Europe.

Vertical loops are generally considered when land surface is limited. Wells are bored to depths that typically range from 75 to 300 ft (22.9 to 91.4 m) deep. The closed-loop pipes are inserted into the vertical well. Typical piping requirements range from 200 to 600 ft per system cooling ton (17.4 to 52.2 m/kW), depending on soil and temperature conditions.

Multiple wells are typically required with well spacing not less than 15 ft (4.6 m) in the northern climates and not less than 20 ft (6.1 m) in southern climates to achieve the total heat-transfer requirements. A 300–500 ton capacity system can be installed on 1 acre of land, depending on soil conditions and ground temperature. There are three basic types of vertical-system heat exchangers: U-tube, divided-tube, and concentric-tube (pipe-in-pipe) system configurations.

- *Advantages*: Requires less total pipe length than most closed-loop designs; requires the least pumping energy of closed-loop systems; requires least amount of surface ground area; ground temperature typically not subject to seasonal variation.

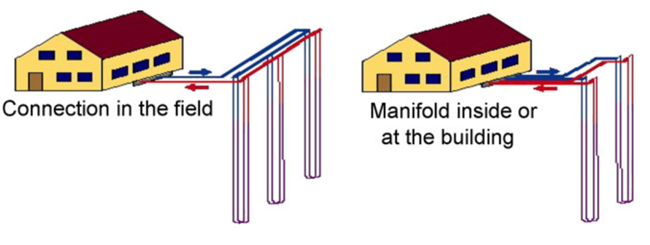

Fig. 10. Borehole heat exchangers (double-U-pipe).

- *Disadvantages*: Requires drilling equipment; drilling costs frequently higher than horizontal trenching costs; some potential for long-term heat build-up underground with inadequately spaced boreholes.

5.4. Submerged loops

If a moderately sized pond or lake is available, the closed-loop piping system can be submerged. Some companies have installed ponds on facility grounds to act as ground-coupled systems; ponds also serve to improve facility aesthetics. Submerged-loop applications require some special considerations, and it is best to discuss these directly with an engineer experienced in the design applications. This type of system requires adequate surface area and depth to function adequately in response to heating or cooling requirements under local weather conditions.

In general, the submerged piping system is installed in loops attached to concrete anchors. Typical installations require around 300 ft of heat-transfer piping per system cooling ton (26.0 m/kW) and around 3000 ft^2 of pond surface area per ton (79.2 m^2/kW) with a recommended minimum one-half acre total surface area. The concrete anchors act to secure the piping, restricting movement, but also hold the piping 9 to 18 in (22.9 to 45.7 cm) above the pond floor, allowing for good convective flow of water around the heat-transfer surface area.

It is also recommended that the heat-transfer loop be at least 6 to 8 ft (1.8 to 2.4 m) below the pond surface, preferably deeper. This maintains adequate thermal mass even in times of extended drought or other low-water conditions. Rivers are typically not used because they are subject to drought and flooding, both of which may damage the system.

- *Advantages*: Can require the least total pipe length of closed-loop designs; can be less expensive than other closed-loop designs if body of water available.
- *Disadvantages*: Requires a large body of water and may restrict lake use (i.e., boat anchors).

5.5. Open-loop systems

Open-loop systems use local groundwater or surface water (i.e., lakes) as a direct heat-transfer medium instead of the heat-transfer fluid described for the closed-loop systems. These systems are sometimes referred to specifically as ‘‘groundwater source heat pumps’’ to distinguish them from other GSHPs. Open-loop systems consist primarily of extraction wells, extraction and reinjection wells, or surface water systems. A variation on the extraction well system is the standing column well. This system reinjects the majority of the return water back into the source well, minimising the need for a reinjection well and the amount of surface discharge water. There are several special factors to consider in open-loop systems. One major factor is water quality. In open-loop systems, the primary heat exchanger between the refrigerant and the groundwater is subject to fouling, corrosion, and blockage. A second major factor is the adequacy of available water. The required flow rate through the primary heat exchanger between the refrigerant and the groundwater is typically between 1.5 and 3.0 gallons per minute per system cooling ton (0.027 and 0.054 L/s-kW). This can add up to a significant amount of water and can be affected by local water resource regulations. A third major factor is what to do with the

discharge stream. The groundwater must either be re-injected into the ground by separate wells or discharged to a surface system such as a river or lake. Local codes and regulations may affect the feasibility of open-loop systems.

Depending on the well configuration, open-loop systems can have the highest pumping load requirements of any of the ground-coupled configurations. In ideal conditions, however, an open-loop application can be the most economical type of ground-coupling system.

- *Advantages*: Simple design; lower drilling requirements than closed-loop designs; subject to better thermodynamic performance than closed-loop systems because well(s) are used to deliver groundwater at ground temperature rather than as a heat exchanger delivering heat-transfer fluid at temperatures other than ground temperature; typically lowest cost; can be combined with potable water supply well; low operating cost if water already pumped for other purposes, such as irrigation.
- *Disadvantages*: Subject to various local, state, and federal clean water and surface water codes and regulations; large water flow requirements; water availability may be limited or not always available; heat pump heat exchanger subject to suspended matter, corrosive agents, scaling, and bacterial contents; typically subject to highest pumping power requirements; pumping energy may be excessive if the pump is oversized or poorly controlled; may require well permits or be restricted for extraction; water disposal can limit or preclude some installations; high cost if reinjection well required.

This type is characterised by the fact that the main heat carrier, ground water, flows freely in the underground, and acts as both a heat source/sink and as a medium to exchange heat with the solid earth. Main technical part of open systems is ground-water wells, to extract or inject water from/to water bearing layers in the underground ("aquifers"). In most cases, two wells are required ("doublette"), one to extract the groundwater, and one to re-inject it into the same aquifer it was produced from (Fig. 11).

With open systems, a powerful heat source can be exploited at comparably low cost. On the other hand, groundwater wells require some maintenance, and open systems in general are confined to sites with suitable aquifers. The main requirements are:

- Sufficient permeability to allow production of the desired amount of groundwater with little draw down.
- Good groundwater chemistry e.g., low iron content to avoid problems with scaling, clogging and corrosion.

Open systems tend to be used for larger installations. The most powerful GSHP system worldwide uses groundwater wells to supply ca. 10 MW of heat and cold to a hotel and offices.

6. Heat pump capabilities

Factors that can effect the life-cycle efficiency of a heat pump:

- Local method of electricity generation.
- Climate.

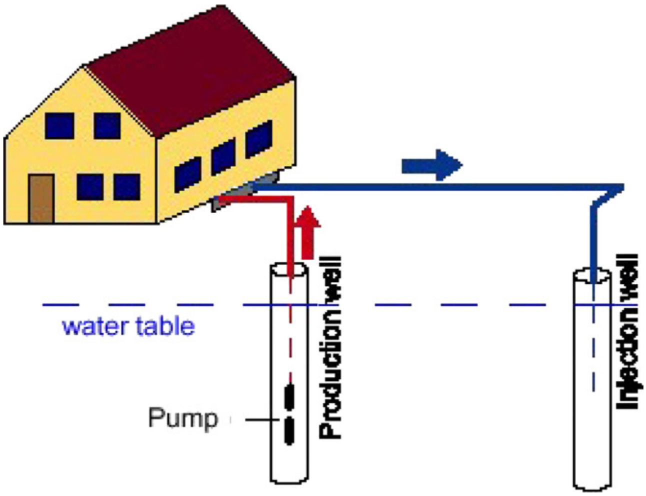

Fig. 11. Groundwater heat pump doublette.

- Type of heat pump (ground vs. air source).
- Refrigerant used.
- Thermostat controls.
- Size of the heat pump.
- Quality of work during installation.
- Energy efficiency of home's layout, insulation and ducts.
- Safeguards against damage to coils from construction, gardening equipment, etc.

A heat pump is a machine, which moves heat from a low-temperature reservoir to a higher-temperature reservoir under supply of work. Common examples are: gas compression heat pumps, phase change heat pumps (Fig. 12), thermoelectric heat pumps that use the Peltier effect, geothermal exchange heat pumps, and vortex tubes. Heat pumps are realised through several physical effects, but they are classified depending on their applications (driving energy, source and sink of heat, or a heat pump which is basically a refrigeration machine). Refrigerators, air conditioners, and some heating systems are all common applications of heat pumps [10].

Heat pumps function by moving (or pumping) heat from one place to another. Like a standard air-conditioner, a heat pump takes heat from inside a building and dumps it outside. The difference is that heat pumps can be reversed to take heat from a heat source outside and pump it inside. Heat pumps use electricity to operate pumps that alternately evaporate and condense a refrigerant fluid to move that heat. In the heating mode, heat pumps are far more "efficient" at converting electricity into usable heat because the electricity is used to move heat, not to generate it. The most common type of heat pump, an air-source heat pump, uses outside air as the heat source during the heating season and the heat sink during the air-conditioning season (Table 2).

An easy way to imagine how a heat pump works is to imagine the heat in a given space—say the volume of a football (or soccerball). The air within the volume of the ball has say 100 units of heat. This air is then compressed to the size of ping-pong ball (table tennis ball);

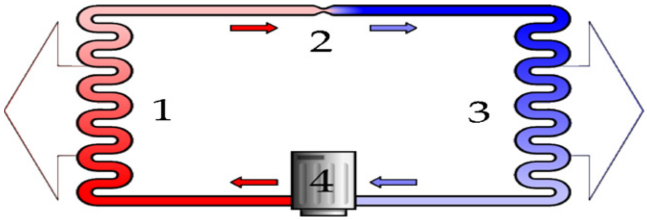

Fig. 12. Diagram of a phase change heat pump: (1) condensator coil, (2) expansion valve, (3) evaporator coil and (4) compressor.

Table 2
Geothermal heat pumps

Environmentally responsible	Saves money up to	Other benefits
No combustion	65% vs. electric resistance heat	Long-lived, proven technology
No ammonia	35% vs. fossil fuels	Can provide almost free hot water
Limited refrigerant charge	45% vs. air source heat pumps	Quiet inside and out

it still contains the same 100 units of heat, but the heat is much more concentrated and thus the average heat per volume unit is much higher. The ping-pong volume of heat is then moved from the heat source area to the target area that has a lower per volume concentration of heat. Since the heat of the ping-pong ball volume is now at higher concentration than the surrounding heat, the heat is given off until the ping-pong ball volume heat reaches the same concentration of heat as the surrounding area. The ping-pong ball volume is then moved outside the target area back to the heat source area and allowed to expand. In expanding the volume of refrigerant in the ping-pong ball is expanded to the size of the football, and the heat energy per unit volume is now well below 100 units enabling the expanded refrigerant to absorb heat from the surrounding area. The compressor unit creates the pressure difference which causes this cycle to endlessly repeat as long as the heat pump system is running.

When comparing the performance of heat pumps, it is best to avoid the word "efficiency", as it has many different meanings. The term coefficient of performance or COP is used to describe the ratio of heat output to electrical power consumption. A typical heat pump has a COP of about four, whereas a typical electric heater has a COP of one, indicating units of heat exchange performance per units of electrical power input (resistive electric heat being 100% efficient whereas heat pump heating offering up to 400% efficiency) [11].

The COP of a heat pump is restricted by the second law of thermodynamics:

$$\mathrm{COP}_{\mathrm{heating}} = (\Delta Q_{\mathrm{hot}}/\Delta A) \leqslant (T_{\mathrm{hot}}/T_{\mathrm{hot}} - T_{\mathrm{cool}}) = 1/\eta_{\mathrm{carnotcycle}}, \tag{1}$$

$$\mathrm{COP}_{\mathrm{cooling}} = (\Delta Q_{\mathrm{cool}}/\Delta A) \leqslant (T_{\mathrm{cool}}/T_{\mathrm{hot}} - T_{\mathrm{cool}}). \tag{2}$$

All temperatures T are measured in Kelvin.

Commercial heat pump technologies are currently in a stage of rapid improvement: the COP for commercially available heat pumps has risen in the last 5 years from 3 to 4 and

even (in a few cases) 5. As a result heat pumps are becoming popular choices for home-heating. Two common types of heat pumps for home heating are air-source and GSHPs depending on whether heat is transferred from the air or from the ground.

7. Heat pump types and arrangements

The two major types of heat pumps are the water-to-air heat pump and the water-to-water heat pump. Water-to-air units deliver either hot air or cold air to the space using water or glycol solution as the transfer medium and the ground as the heat sink or heat source. The major components include casing, compressor, expansion valve, reversing valve, refrigerant-to-water heat exchanger, supply fan, and connections for the source water "in" source water "out" condensate drain, controls, and other accessories:

- The top pipe is recommended to 2 ft below the frost line.
- The trench depth is usually 5 ft.
- The distance between the trenches is 7 to 8 ft.
- A horizontal heat exchanger, located under the asphalt surface, may operate at higher temperatures in summer and a lower temperature in winter.
- The building height is not an issue in the vertical designs.
- The vertical bore fields require anywhere from 60 to 275 sq ft of ground-surface area per ton of block load.
- The borehole depths range from 150 to 500 ft.
- The spacing between the bores is normally 15 ft.
- The vertical design is limited to buildings of about six stories or less.

7.1. Water-to-water heat pumps

Water-to-water units produce either chilled water (usually 45 °F) or hot water (usually not over 130 °F) using water or glycol solution as the heat-transfer medium and the ground as the heat sink or the heat source. The major components of this unit include casing, compressor, expansion valve, reversing valve, refrigerant-to-water heat exchanger, and connections for source water "in" source water "out" system (or load) side-water "supply" system (or load) side-water "return".

7.2. Water-to-air vs. "water-to-water" heat pumps

Water-to-air heat pumps are excellent for applications where each individual zone requires a separate control. This application has increased maintenance and electrical demand because there is no way to take advantage of load diversity. Water-to-water heat pumps are very good candidates where the building occupancies allow the advantage of diversity. Several water-to-water heat pumps can be grouped together to create a central cooling and heating plant to serve several air-handling units. The system can be sized for this diversity, rather than for the individual peaks. This application has advantages of better control, centralised maintenance, redundancy, and flexibility. The disadvantage is that the initial costs tend to be higher, especially if the four-pipe system is used. The water-to-water heat pumps can also be used for pre-heating/pre-cooling and hydronic heating applications.

Geothermal heating is more expensive to install initially, than electrical or gas-fired heating systems. However it is cheaper to run, has lower maintenance costs, and is cleaner in use than other sources of heating (Fig. 13).

8. Heat pump efficiency

Three types of heat pumps are typically available for residences: (1) air-to-air, (2) water source, and (3) ground source. Heat pumps collect heat from the air, water, or ground outside homes and concentrate it for use inside. Heat pumps operate in reverse to cool homes by collecting the heat inside the house and effectively pumping it outside.

Heat pumps have both heating and cooling ratings—both in terms of capacity and efficiency. Capacity ratings are generally in Btu per hour or tons (one ton equals 12,000 Btu/h). Heating efficiency for air source heat pumps is indicated by the HSPF. The HSPF tells the ratio of the seasonal heating output in Btu's divided by the seasonal power consumption in Watt-hours. A heat pump can supply two to three times as much heat as it consumes in electricity because it moves energy from outside to inside (or vice versa). Heat pump efficiency varies with outdoor temperature. The performance of an air source heat pump in heating mode decreases with the drop in outside air temperature. The actual seasonal efficiency (as opposed to the rating) is therefore higher in a mild climate than in a severe cold climate.

In the cooling mode, a heat pump operates exactly like a central air conditioner. The SEER is analogous to the HSPF but tells the seasonal cooling performance. Federal efficiency standards require that conventional heat pumps have an HSPF rating of at least 6.8 and a SEER rating of at least 10.0. The most efficient air source heat pumps have an HSPF rating between 9.0 and 10.0 and a SEER above 14 or so [12].

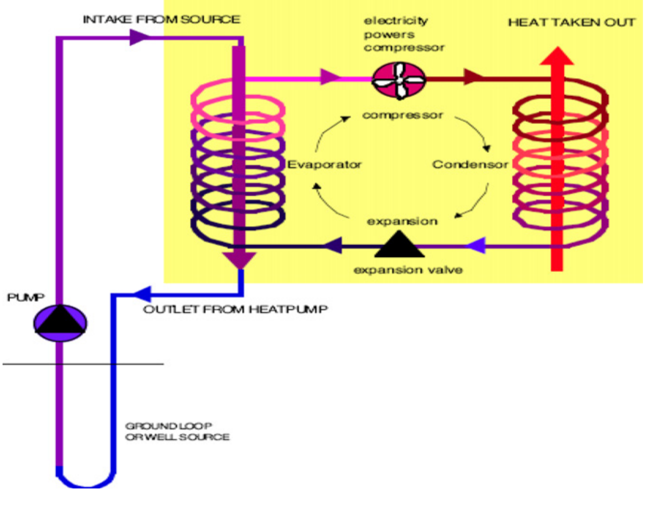

Fig. 13. Layout of heat pump system.

9. Environmental benefits

Geothermal/GSHPs work with the environment to provide clean, efficient, and energy saving heating and cooling year round. GSHPs use less energy than alternative heating and cooling systems, helping to conserve our natural resources. GSHPs are housed entirely within the building and underground. They are quiet, pollution free and do not detract from the surrounding landscape (Fig. 14).

Governments and energy planners prefer EE technology because it is an environmentally benign technology, with no emissions or harmful exhaust. The EE industry was the first to move away from damaging chlorofluorocarbons (CFCs). Although EE units require electricity to operate the components, a high COP means that EE systems provide a significant reduction in the level of CO_2, SO_2 and NO_x emissions (all linked with the issue of GHG emissions and global warming) [13].

9.1. Consumers

Geothermal/GSHPs offer consumers a heating, cooling, and hot water system that are cost saving, reliable, efficient, and environmentally sound. The unique flexibility of GSHPs allows them to be used for residential and commercial buildings all across the US, Canada, and Europe. GSHP systems can be installed in new buildings and as retrofits in older buildings.

9.2. Utilities

Geothermal/GSHPs are a proven technology, and are highly efficient. GSHP systems help electric utilities stabilise demand loads and become more competitive with other energy sources. They are fast becoming the most reliable and competitive heating systems available.

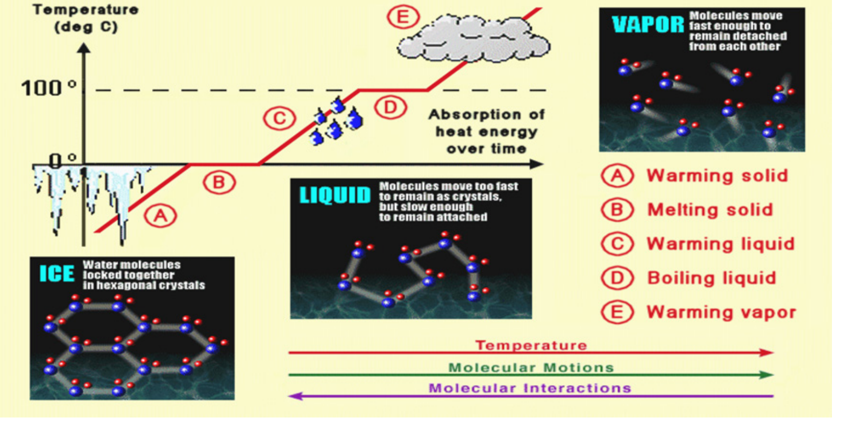

Fig. 14. Principle of ground-source energy.

9.3. Savings

Earth-energy technology may be more expensive to install than some natural gas, oil or electric heating units, but they are very competitive with any type of combination heating/cooling system. For this reason, heat pumps are most attractive for applications requiring both heating and cooling.

An open-loop water-source system for an average residence may cost $10,000, while a closed-loop ground-source system may cost as much as $20,000. However, annual operating costs would be as low as $850 compared to $2000 or more for conventional heating/cooling systems [14].

The savings available with an EE heat pump will reflect the size of the house, its heat loss and level of insulation, as well as the sizing of the EE unit, its balance point, its COP, local climate and energy costs, the lifestyle habits, the efficiency of alternate heating systems, configuration of loop, interior temperature setting, ductwork (on retrofits), site accessibility for equipment, and the options selected.

9.4. Global warming impacts of GSHPs compared to other heating–cooling systems

Heat pumps can significantly reduce primary energy use for building heating and cooling. Heat pumps utilise renewable or solar energy stored in the ground near the surface (ground-source). The renewable component (66%) displaces the need for primary fuels, which, when burned, produce GHGs and contribute to global warming.

This analysis was to estimate the total equivalent warming impact (TEWI) of GSHPs compared to other heating and cooling systems in residential, commercial and institutional buildings. The modelling results show significant emission reductions. The impact of heating only is examined in residential buildings, whereas both heating and cooling impacts are examined in commercial and institutional buildings.

Significant emission reductions are available through the application of GSHPs in both residential and commercial buildings. For the models studied here, residential fossil fuel heating systems produced anywhere from 1.2 to 36 times the equivalent CO_2 emissions of GSHPs. CO_2 emission reductions from 15% to 77% were achieved through the use of GSHPs [15].

GSHP equipment is widely available throughout Europe. The equipment is competitive on a life-cycle cost basis with those systems examined, particularly in those markets where air-conditioning is desired. There is unlikely to be a potentially larger mitigating effect on GHG emissions and the resulting global warming impact of buildings from any other current, market-available single technology, than from GSHPs.

10. Ground temperatures

At depths below four feet, ground temperature stays a constant 50 to 55 °F year-round. During the winter, a geothermal system absorbs this extra heat from the earth and transfers it into homes. During the summer, the system takes heat from indoors and moves it back underground. Annual air temperature, moisture content, soil type and vegetative cover (i.e., trees and plants) all have an effect on underground soil temperature (Figs. 15–17). As you might expect, the earth's temperature changes in response to weather changes, but there is less change at greater depths.

11. Energy efficiency

In general, energy efficiency is calculated as the "useful work" or "energy delivered" divided by the amount of energy supplied to do that work. With heat pumps, energy efficiency is measured in two different ways.

Heating efficiency is expressed as a COP. The higher the COP, the more efficient the system. For example, a residential-sized geothermal system might have a COP of 3.4 or higher, meaning for every one unit of energy used to power the system, more than three units are put back into the home as heat. This compares to efficiencies of 0.92 for a high-efficiency natural gas furnace.

Cooling efficiency is measured as an energy efficiency ratio (EER). The higher the EER, the more efficient the system. Both COP and EER are dependent on many factors, and that high-efficiency equipment comes with a higher price tag—but the energy savings can pay back in the difference in just a few years.

12. The future

Energy prices have increased significantly since the second half of 1999. Plans already drafted at the end of the 1990s, but partly delayed, by Indonesia, Philippines and Mexico aim at an additional 2000 Mw_e before 2010. In the direct use sector, China has the most ambitious target: substitution of 13 million tons of polluting coal by geothermal energy.

The short to medium term future of geothermal energy is encouraging, providing some hurdles that have recently slowed its growth are overcome. Among them: the Far Eastern economic crisis (especially in Indonesia and Philippines, which had ambitious development plans); the strong production decline at the Geysers field in USA; the extended period of low-energy prices. Where possible, actions are being taken to improve the situation. At The Geysers an effluent pipeline (to be completed by 2002) is under construction from the town of Santa Rosa, so as to inject into the reservoir as much wastewater as is being produced, thus increasing the field potential.

Fig. 15. Air and ground temperatures.

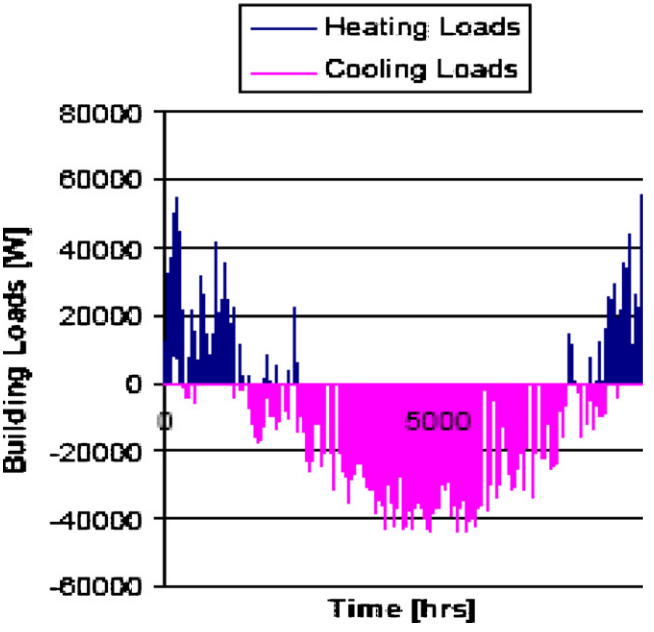

Fig. 16. Annual hourly building heating and cooling loads [16].

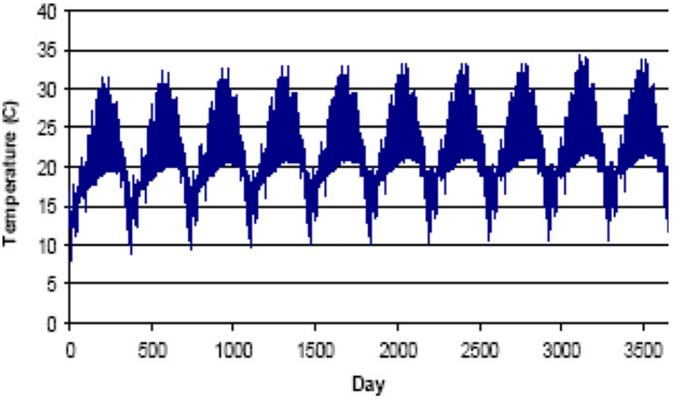

Fig. 17. Entering fluid temperatures to the heat pump (°C) [16].

Improved use of hydrothermal resources, limitation of front-end costs and increased ground heat extraction are the keys to a steady development of conventional geothermal energy. Installation of a large number of binary power plants will increase electricity production from wide geographical areas underlain by medium-temperature resources: a good example is the Altheim plant just inaugurated in Austria, which has added power production to district heating with 106 °C water. Heat readily available

in spaces can be optimised by adding compatible uses. New horizons for geothermal energy can be opened up with fresh applications, for example drinking water production on islands and in coastal areas with scarce resources (e.g., the project starting in 2001 on Milos, Greece). Finally, GSHP systems can be replicated in many parts of the world.

13. Conclusions

A ground-source heat pump (GSHP) system utilises the earth, ground water, or surface water as a heat source/sink for providing heating and cooling. The GSHP is generally recognised to be one of the most outstanding technologies of heating and cooling in both residential and commercial buildings, because it provides high coefficient of performance (COP), up to 3–4 for an indirect heating system and 3.5–5 for a direct heating system. The main benefit of using GSHPs is that the temperature of the subsurface is not subject to large variations experienced by air. It is currently the most common thermal energy source for the heat pumps, and so would allow construction of more efficient systems with superior performance. GSHPs do not need large cooling towers and their running costs are lower than conventional heating and air-conditioning systems. As a result, GSHPs have increasingly been used for building heating and cooling with annual rate of increase of 10% in recent years. With increasing worldwide awareness of the serious environmental problems due to fossil fuel consumption, efforts are being made to develop energy-efficient and environmentally friendly systems by utilisation of non-polluting renewable energy sources, such as solar energy, industrial waste heat or geothermal water. GSHPs are suitable for heating and cooling of buildings and so could play a significant role in reducing CO_2 emissions.

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